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## SPECIFICATION

## TITLE OF THE INVENTION

Method of and apparatus for communication

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## TECHNICAL FIELD

The present invention relates to a communication apparatus in which a multicarrier modulation and demodulation technique is adopted. More particularly, this invention relates to the method of and the apparatus for communication which makes it possible to implement data communication using an existing communication line by means of the DMT (Discrete Multi Tone) modulation and demodulation technique or the OFDM (Orthogonal Frequency Division Multiplex) modulation and demodulation technique. However, the present invention can be applied not only to communication apparatuses which conduct data communication by means of the DMT modulation and demodulation technique, but also to all the communication apparatuses which conduct wire communication and radio communication via ordinary communication lines by using the multicarrier modulation and demodulation technique and the single modulation and demodulation technique.

25 BACKGROUND ART



Operation of a receiver system of the conventional communication apparatus in which the OFDM modulation and demodulation technique is adopted as the multicarrier modulation and demodulation technique will now be explained briefly. When data communication using the OFDM modulation and demodulation technique is conducted in the same way as the foregoing description, the receiver system conducts low-pass filtering on received data (the aforementioned transmission data), then converts its analog waveform to a digital waveform by using an A/D converter, and conducts time domain adaptive equalization processing by using a time domain equalizer.

reproduced.

However, the conventional communication apparatus in which the OFDM modulation and demodulation technique is adopted has a problem that there is room for improvement in the configuration of the transmitter system and the receiver system from a viewpoint of "further increase of the transmission rate" and that it cannot be said that "a high transmission efficiency" and "function flexibility" are utilized to the utmost and an optimum transmission rate is accomplished.

## DISCLOSURE OF THE INVENTION

of the present invention adapts a multicarrier modulation and demodulation technique. This communication apparatus comprises a transmitter unit which converts a transmission symbol to a half symbol and conducts communication in such  
5 a state that a predetermined power difference is given between even-numbered subcarriers and odd-numbered subcarriers which is interference components at time of demodulation. This communication apparatus further comprises a receiver unit which conducts predetermined  
10 Fourier transform to extract even-numbered subcarriers on a received symbol converted to the half symbol, and demodulates data assigned to the subcarriers, which, on the other hand, conducts inverse Fourier transform on the data assigned to the even-numbered subcarriers, and generates  
15 a first symbol formed of temporal waveforms of the even-numbered subcarriers, which subsequently removes the first symbol component from the received symbol, generates a second symbol formed of temporal waveforms of odd-numbered subcarriers, and generates a third symbol by adding a symbol  
20 obtained by copying and inverting the second symbol, after the second symbol, and which finally conducts predetermined Fourier transform to extract odd-numbered subcarriers on the third symbol, and demodulates data assigned to the subcarriers.

25 In the above-mentioned communication apparatus, the

receiver unit conducts inverse Fourier transform on data assigned to the odd-numbered subcarriers, generates a fourth symbol formed of temporal waveforms of odd-numbered subcarriers, then removes the fourth symbol component from  
5 the received symbol, and thereafter conducts demodulation processing by using the received symbol with the fourth symbol component removed.

In the above-mentioned communication apparatus, the transmitter unit spreads (multiplexes) transmission data  
10 assigned to a  $(2i-1)$ th subcarrier and a  $2i$ th subcarrier which are adjacent to each other, with a predetermined spreading code, conducts inverse Fourier transform on the signal subjected to the spreading, and thereby generates the transmission symbol, and the receiver unit despreads  
15 (demultiplexes) the demodulated data with the spreading code, and reproduces original transmission data assigned to the  $(2i-1)$ th subcarrier and the  $2i$ th subcarrier which are adjacent to each other.

The communication apparatus according to still another  
20 aspect of this invention functions as a transmitter in which a multicarrier modulation and demodulation technique is adopted. This communication apparatus comprises a transmitter unit which converts a transmission symbol to a half symbol and conducts communication in such a state  
25 that a predetermined power difference is given between

even-numbered subcarriers and odd-numbered subcarriers which is interference components at time of demodulation.

The above-mentioned communication apparatus further comprises a multiplexing unit which spreads (multiplexes) transmission data assigned to a  $(2i-1)$ th subcarrier and a  $2i$ th subcarrier which are adjacent to each other, with a predetermined spreading code. Moreover, the transmitter unit conducts inverse Fourier transform on the signal subjected to the spreading, and thereby generates the transmission symbol.

The communication apparatus according to still another aspect of this invention functions as a receiver in which a multicarrier modulation and demodulation technique is adopted. The communication apparatus comprises, a first demodulation unit (which corresponds to a TEQ 2, a 128 complex FFT 3, an FEQ 4, and a decoder 5) which conducts predetermined Fourier transform to extract even-numbered subcarriers on a received symbol converted to the half symbol, and demodulates data assigned to the subcarriers, a first symbol generation unit (which corresponds to an inverse FEQ transform section 6, a 128 complex IFFT 7, and an inverse TEQ transform section 8) which conducts inverse Fourier transform on the data assigned to the even-numbered subcarriers, and generates a first symbol formed of temporal waveforms of the even-numbered subcarriers, a second symbol

generation unit (which corresponds to a subtracter 9) which removes the first symbol component from the received symbol, and generates a second symbol formed of temporal waveforms of odd-numbered subcarriers, a third symbol generation unit  
 5 (which corresponds to a symbol generation section 10) which generates a third symbol by adding a symbol obtained by copying and inverting the second symbol, after the second symbol, and a second demodulation unit (which corresponds to a TEQ 11, a 256 complex FFT 12, an FEQ 13, and a decoder  
 10 14) which conducts predetermined Fourier transform to extract odd-numbered subcarriers on the third symbol, and demodulates data assigned to the subcarriers.

The above-mentioned communication apparatus further comprises, a fourth symbol generation unit (which  
 15 corresponds to an inverse FEQ transform section 15, a 256 complex IFFT 16, and an inverse TEQ transform section 17) which conducts inverse Fourier transform on data assigned to the odd-numbered subcarriers, and generates a fourth symbol formed of temporal waveforms of odd-numbered  
 20 subcarriers, and a removal unit (which corresponds to a subtracter 1) which removes the fourth symbol component from the received symbol. Thereafter, a demodulation processing is conducted by using the received symbol with the fourth symbol component removed.

25 The above-mentioned communication apparatus further



comprises a demultiplexing unit (which corresponds to a demultiplexing section 74) which despreads (demultiplexes) the demodulated data, and reproduces original transmission data assigned to the  $(2i-1)$ th subcarrier and the  $2i$ th subcarrier which are adjacent to each other.

The communication method according to still another aspect of this invention comprises, a transmission step which converts a transmission symbol to a half symbol and conducts communication in such a state that a predetermined power difference is given between even-numbered subcarriers and odd-numbered subcarriers which is interference components at time of demodulation, a first demodulation step which conducts predetermined Fourier transform to extract even-numbered subcarriers on a received symbol converted to the half symbol, and demodulates data assigned to the subcarriers, a first symbol generation step which conducts inverse Fourier transform on the data assigned to the even-numbered subcarriers, and generates a first symbol formed of temporal waveforms of the even-numbered subcarriers, a second symbol generation step which removes the first symbol component from the received symbol, and generates a second symbol formed of temporal waveforms of odd-numbered subcarriers, a third symbol generation step which generates a third symbol by adding a symbol obtained by copying and inverting the second symbol, after the second

symbol, and a second demodulation unit which conducts predetermined Fourier transform to extract odd-numbered subcarriers on the third symbol, and demodulates data assigned to the subcarriers.

5       The above-mentioned communication method further comprises, a fourth symbol generation step which conducts inverse Fourier transform on data assigned to the odd-numbered subcarriers, and generates a fourth symbol  
10 and a removal step which removes the fourth symbol component from the received symbol, and thereafter demodulation processing is conducted by using the received symbol with the fourth symbol component removed.

      The above-mentioned communication method further  
15 comprises, a multiplexing step which spreads (multiplexes) transmission data assigned to a  $(2i-1)$ th subcarrier and a  $2i$ th subcarrier which are adjacent to each other, with a predetermined spreading code, conducts inverse Fourier transform on the signal subjected to the spreading, and  
20 thereby generates the transmission symbol, and a demultiplexing step which despreads (demultiplexes) the demodulated data with the spreading code, and reproduces original transmission data assigned to the  $(2i-1)$ th subcarrier and the  $2i$ th subcarrier which are adjacent to  
25 each other.



drawings. The present invention is not restricted by the  
embodiments.

Fig. 1 is a diagram showing a configuration of a first  
embodiment of a communication apparatus according to the  
present invention. More specifically, Fig. 1 is a diagram  
showing a configuration of a receiver side which is a feature  
of the present embodiment.

A communication apparatus according to the present embodiment has configurations of both the transmitter side and the receiver side. In addition, since the communication apparatus has a data error correction capability of high precision owing to a turbo encoder and a turbo decoder, an excellent transmission characteristic is obtained in data communication and audio communication. For convenience of explanation, it is assumed that the present embodiment has both configurations. For example, however, a transmitter having only the configuration of the transmitter side may be supposed. On the other hand, a receiver having only the configuration of the receiver side may be supposed.

For example, in the configuration of the receiver side of Fig. 1, reference numeral 1 denotes a subtracter, 2 denotes a time domain equalizer section (TEQ), 3 denotes a fast Fourier transform section (128 complex FFT) which extracts, for example, only 64 even-numbered subcarriers from among



as an ADSL (Asymmetric Digital Subscriber Line) communication technique whereby fast digital communication of several megabits/second is conducted by using an existing telephone line, and an HDSL (high-bit-rate Digital Subscriber Line) communication technique. This technique is standardized in T1.413 of the ANSI and so on.

Fig. 2 is a diagram showing a general configuration example of a transmitter system of a communication apparatus in which the DMT modulation and demodulation technique is adopted. With reference to Fig. 2, in the transmitter system, transmission data are multiplexed by a multiplex/sync control (which corresponds to illustrated MUX/SYNC CONTROL) 41. Error detection codes are added to the multiplexed transmission data in cyclic redundancy check (which corresponds to CRC) 42 and 43. In addition, addition of FEC codes and scramble processing are conducted in forward error correction (which correspond to SCRAM&FEC) 44 and 45.

Between the multiplex/sync control 41 and a tone ordering 49, there are two paths. One of them is an interleaved data buffer path, which includes an interleave (INTERLEAVE) 46. The other of them is a fast data buffer path, which does not include the interleave. The interleaved data buffer path, on which the interleave processing is conducted, caused a longer delay.

25           Thereafter, the transmission data is subject to rate

conversion processing in rate converters (which correspond to RATE-CONVERTOR's) 47 and 48, and subject to tone ordering processing in a tone ordering (which corresponds to TONE ORDERING) 49. On the basis of the transmission data  
5 subjected to the tone ordering processing, constellation data is created (turbo decoding is included) in a constellation encoder/gain scaling (which corresponds to CONSTELLATION ENCODER AND GAIN SCALING) 50. Inverse fast Fourier transform is conducted in an inverse fast Fourier  
10 transform section (which corresponds to IFFT) 51.

Fig. 3 is a diagram showing a general configuration  
example of a receiver system of a communication apparatus  
in which the DMT modulation and demodulation technique is  
adopted. With reference to Fig. 3, in the receiver system,  
filtering processing is conducted on received data (the  
aforementioned transmission data) and then an analog  
waveform is converted to a digital waveform in an analog

processing/analog-digital converter (which corresponds to ANALOG PROCESSING AND ADC) 141. Time domain adaptive equalization processing is conducted in a time domain equalizer (which corresponds to TEQ) 142.

5       As for the data subjected to execution of the time domain adaptive equalization processing, serial data is converted to parallel data in an input serial/parallel buffer (which corresponds to INPUT SERIAL/PARALLEL BUFFER) 143. The parallel data is subject to fast Fourier transform in  
10 a fast Fourier transform section (which corresponds to FFT) 144. Thereafter, frequency domain adaptive equalization processing is conducted in a frequency domain equalizer (which corresponds to FEQ) 145.

      The data subjected to execution of the frequency domain  
15 adaptive equalization processing is converted to serial data by decoding processing (turbo decoding) and tone ordering processing conducted in a constellation decoder/gain scaling (which corresponds to CONSTELLATION DECODER AND GAIN SCALING) 146 and a tone ordering (which corresponds to TONE  
20 ORDERING) 147. Thereafter, there is conducted processing such as rate conversion processing in rate converters (which correspond to RATE-CONVERTER's) 148 and 149, deinterleave processing in a deinterleave section (which corresponds to DEINTERLEAVE) 150, FEC processing and descramble processing  
25 in forward error correction sections (which correspond to





section 144 correspond to the 128 complex FFT 3 of Fig. 1. The frequency domain equalizer 145 corresponds to the FEQ 4 of Fig. 1. The subsequent circuit corresponds to the decoder 5.

For example, in the encoder of Fig. 4(a), 21 denotes a turbo encoder capable of providing performance which is near the Shannon's limit owing to the adoption of a turbo code as an error correction code. For example, the turbo encoder 21 outputs information bits of 2 bits and redundancy bits of 2 bits in response to information bits of 2 bits. Here, respective redundancy bits are generated so that correction capabilities for respective information bits will become uniform on the receiver side.

On the other hand, in the decoder of Fig. 4(b), 22 denotes a first decoder which calculates a logarithmic likelihood ratio from a received signal  $L_{cy}$  (which corresponds to received signals  $y_2, y_1, y_a$  explained later), 23 and 27 adders, 24 and 25 interleavers, 26 a second decoder which calculates a logarithmic likelihood ratio from a received signal  $L_{cy}$  (which corresponds to received signals  $y_2, y_1, y_a$  explained later), 28 a deinterleaver, 29 a first decision unit which makes a decision on an output of the first decoder 22 and outputs an estimated value of an original information bit sequence, 30 a first R/S decoder which decodes a Reed-Solomon code and outputs an information bit sequence having a higher precision, 31 a second decision unit which makes a decision on an output of the second decoder 26 and outputs an estimated value of an original information bit sequence, 32 a second R/S decoder which decodes a Reed-Solomon code and outputs an information bit sequence having a higher precision, and 33 a third decision unit which makes a complex decision on  $L_{cy}$  (which corresponds to received signals  $y_3, y_4, \dots$  explained later).

First, operation of the encoder shown in Fig. 4(a) will be explained. In the present embodiment, for example, the 16 QAM technique is adopted as quadrature amplitude modulation (QAM). In the encoder of the present embodiment, turbo encoding is carried out only for input data of two

low-order bits, and input data of the remaining high-order bits is output as it is. In other words, in the present embodiment, turbo encoding having an excellent error correction capability is carried out for two low-order bits of four signal points having a possibility of being degraded in characteristics (i.e., four points which are nearest in distance between signal points), and a soft decision is made on the receiver side. On the other hand, the remaining high-order bits which are low in possibility of being degraded in characteristics are output as is, and a complex decision is made on the receiver side.

20 In Fig. 5, 35 denotes a first recursive systematic convolutional encoder which conducts convolutional encoding on transmission data  $u_1$  and  $u_2$  corresponding to the information bit sequence and outputs redundancy data  $u_a$ , 36 and 37 denote interleavers, 38 denotes a second recursive systematic convolutional encoder which conducts

In the turbo encoder 21, occurrence of an offset in weights of redundancy bits is prevented so that precision of estimation of the transmission data  $u_1$  and  $u_2$  conducted on the receiver side by using the redundancy data  $u_a$  and  $u_b$  may become uniform.

If the encoder shown in Fig. 4(a) is used, it thus becomes possible to improve an error correction capability for a burst data error as an effect of the interleaving. In addition, by interchanging the input of the sequence of the transmission data  $u_1$  and the input of the sequence of the transmission data  $u_2$  between the first recursive systematic convolutional encoder 35 and the second recursive systematic convolutional encoder 38. As a result, it becomes possible to make uniform the precision of estimation of the transmission data  $u_1$  and  $u_2$  conducted on the receiver



l are derived. In the ensuing explanation,  $u_{1k}$  and  $u_{2k}$  are referred to simply as  $u_k$ , and  $u_{1k}'$  and  $u_{2k}'$  are referred to simply as  $u_k'$ .

Subsequently, the adder 23 calculates the external information  $Le(u_k)$  for the second decoder 26 from the logarithmic likelihood ratio which is the result of calculation. In decoding of the first time, however, the  
15 anterior information is not derived, and consequently  $La(u_k)=0$ .

Thereafter, in the adder 27, the external information  
25  $Le(u_k)$  is calculated in the same way as the adder 23. At

this time, the external information rearranged in the deinterleaver 28 is fed back to the first decoder 22 as the anterior information  $\text{La}(u_k)$ .

Finally, the first R/S decoder 30 and the second R/S decoder 32 conducts error check using a Reed Solomon code according to a predetermined method, and finishes the repetition processing in such a stage that the estimated precision is judged to have exceeded a specific criterion. Error correction of the estimated original transmission data is conducted by using a Reed Solomon code in each decision unit. Transmission data of a higher estimation precision



is thus output.

The method of estimation of the original transmission data conducted by the first R/S decoder 30 and the second R/S decoder 32 will now be explained by referring to concrete examples. As concrete examples, three methods will be mentioned. A first method will now be explained. For example, every time the original transmission data is estimated in the first decision unit 29 or the second decision unit 31, the first R/S decoder 30 or the second R/S decoder 32 corresponding thereto alternately conducts error check. In such a stage that either R/S decoder has judged that "there are no errors," the repetition processing using the turbo encoder is finished. And error correction of the estimated original transmission data is conducted by using a Reed Solomon code, and transmission data of a higher estimation precision is output.

A second method will now be explained. Every time the original transmission data is estimated in the first decision unit 29 or the second decision unit 31, the first R/S decoder 30 or the second R/S decoder 32 corresponding thereto alternately conducts error check. In such a stage that both R/S decoders have judged that "there are no errors," the repetition processing using the turbo encoder is finished. And error correction of the estimated original transmission data is conducted by using a Reed Solomon code, and

transmission data of a higher estimation precision is output.

A third method improves the problem of the first and second methods that false correction is conducted if repetition processing is not carried out due to a false judgment that "there are no errors." For example, after the bit error rate is reduced to some degree by carrying out repetition processing a predetermined number of times, error correction of the estimated original transmission data is conducted by using a Reed Solomon code, and transmission data of a higher estimation precision is output.

Thus, if the decoder shown in Fig. 4(b) is used, it becomes possible to accomplish reduction of soft decision processing requiring a large amount of calculation and favorable transmission characteristics, even if constellation is increased due to introduction of the multi-valued modulation technique, by providing turbo decoders which carry out the soft decision processing for two low-order bits of the received signal having a possibility of characteristic degradation and error correction using the Reed Solomon code, and a decision unit which makes a complex decision on other bits of the received signal.

Further, by estimating the transmission data by means of the first R/S decoder 30 and the second R/S decoder 32, the number of times of iteration can be reduced. Thus it

Heretofore, there have been explained basic operation of a communication apparatus in which the multicarrier modulation and demodulation technique is adopted, and operation of a communication apparatus if a turbo code is used in order to obtain favorable transmission characteristics and a high transmission rate. By referring to Fig. 1, there will hereafter be explained a communication apparatus which utilizes "a high transmission efficiency" and "function flexibility," forming features of the multicarrier modulation and demodulation technique, and which accomplishes an optimum transmission rate, from the viewpoint of "further increase of the transmission rate." For convenience of explanation, 128 subcarriers are supposed. For example, it is assumed that 256 complex FFTs are used for demodulation of 128 subcarriers and 128 complex FFTs are used if only 64 even-numbered subcarriers are demodulated from among 128 subcarriers.





Subsequently, the FEQ 4 conducts frequency domain adaptive equalization processing on the 64 extracted even-numbered subcarriers. The decoder 5 conducts decoding processing according to the predetermined method (see Fig. 4(b)), and reproduces the original transmission data after the decision. Data assigned to the even-numbered subcarriers is output as is.

Further, on the receiver side, the inverse FET transform section 6 conducts inverse FEQ transform on the data assigned to the even-numbered subcarriers. Subsequently, the 128 complex IFFT 7 conducts inverse fast Fourier transform on the data subjected to the inverse FEQ transform. And the inverse TEQ transform section 8 conducts inverse TEQ transform on temporal waveforms of even-numbered subcarriers subjected to the inverse fast Fourier transform. As a result, symbols formed of only waveforms of the even-numbered subcarriers are generated (see Fig. 7(a)).

Subsequently, the subtracter 9 removes symbol components formed of only waveforms of the even-numbered subcarriers from the received symbols converted to the half symbols, and extracts symbols (half symbols) formed of only waveforms of odd-numbered subcarriers (see Fig. 7(b)). The symbol generator section 10 copies and inverts the symbol subjected to the subtraction, thereby generates a symbol, adds the generated symbol after the symbol subjected to the

subtraction, using the feature of the odd-numbered subcarriers shown in Fig. 7(b), and thus generates a symbol in the state before conversion to half symbols carried out on the transmitter system.

5           Finally, on the receiver system, the TEQ 11 conducts time domain adaptive equalization processing on the received symbols (full symbols) of the odd-numbered subcarriers. The 256 complex FFT 12 carries out Fourier transform on parallel data subjected to the time domain adaptive  
10 equalization processing. The FEQ 13 conducts frequency domain adaptive equalization processing on the extracted 64 odd-numbered subcarriers. The decoder 14 conducts decoding processing according to the predetermined method (see Fig. 4(b)), and reproduces the original transmission  
15 data after the decision.

For example, if an error has occurred in the demodulated data, the demodulation characteristics can be improved in the present embodiment by repetitively executing processing explained hereafter. For example, the inverse FEQ  
20 transform section 15 conducts inverse FEQ transform on the data assigned to the odd-numbered subcarriers. Subsequently, the 256 complex IFFT 16 conducts inverse fast Fourier transform on the data subjected to the inverse FEQ transform. The inverse TEQ transform section 17 conducts  
25 inverse TEQ transform on the temporal waveforms of the

Thus, in the present embodiment, the communication apparatus of the transmitter side converts transmission symbols to half symbols and transmits them, and the communication apparatus of the receiver side separates even-numbered subcarriers and odd-numbered subcarriers, demodulates only received symbols of even-numbered subcarriers converted to half symbols, then removes symbol components of the even-numbered subcarriers, and thereafter demodulates only the received symbols of odd-numbered subcarriers. As a result, compression on the time axis becomes possible and the transmission capacity can be expanded to approximately twice. Further, in the present embodiment, symbols formed of only the waveforms of odd-numbered subcarriers are fed back, and the odd-numbered subcarriers, which is noise components, can be removed from the received symbols. Owing to such a configuration, the demodulation precision can be remarkably improved.





an orthogonal code.

In Fig. 8(a), 61 denotes a multiplexing section which spreads transmission data by using the known Hadamard sequence, 62 an ordering section, 63 an inverse fast Fourier transform section, and 64 a D/A conversion section. In Fig. 8(b), 71 an A/D conversion section, 72 a half symbol demodulation section, 73 a deordering section, and 74 a demultiplexing section which despreads demodulated data by using the known Hadamard sequence.

Hereafter, operation of the communication apparatus having the aforementioned configuration will be explained. First, on the transmitter side, the multiplexing section 61 spreads transmission data assigned to adjacent odd-numbered subcarriers and subcarriers (such as subcarrier #1 and subcarrier #2, subcarrier #3 and subcarrier #4, ...) by using a known Hadamard sequence. An Hadamard sequence H used as the spreading code can be represented by the following equation (1),

$$H = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} \quad \dots (1)$$

$$\begin{bmatrix} s_1 \\ s_2 \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ -1 & 1 \end{bmatrix}$$

where  $C_1$  and  $C_2$  represent codes, and  $S_1$  and  $S_2$  represent

signals.

For example, representing transmission data  $d_k$  by  $[d_{2i-1}, d_{2i}]$ , the multiplexing section 61 conducts spreading as represented by the following equation (2),

5

$$\begin{bmatrix} x_{2l-1} \\ x_{2i} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} d_{2l-1} \\ d_{2i} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \dots \quad (2)$$

where  $k$  represents  $n$  integers,  $i$  represents  $(n/2)$  integers,  $[x_{2i-1}, x_{2i}]$  represents a transmission signal subjected to spreading, and  $1/2$  in the equation represents a coefficient for normalization.

For example, if the transmission data is  $[d_1=1, d_2=-1]$ , therefore, the transmission signal  $[x_1, x_2]$  after spreading becomes,

$$\begin{aligned} 15 \quad [\mathbf{x}_1, \mathbf{x}_2] &= (1[-1, -1] + (-1)[-1, 1])/2 \\ &= [0, -2]/2 \\ &= [0, -1] \end{aligned}$$

For other subcarriers as well, calculation is conducted in the same way. Thus, in the present embodiment, energy of either of data assigned to the adjacent subcarriers (which correspond to, for example, subcarrier #1 and subcarrier #2, subcarrier #3 and subcarrier #4, ...) is made equal to 0 by spreading (multiplexing) the transmission data.

The ordering section 62 assigns transmission signals

5           Finally, the inverse fast Fourier transform section  
63 conducts inverse fast Fourier transform on data assigned  
to respective subcarriers. In addition, in the same way  
as the first embodiment, the inverse fast Fourier transform  
section 63 converts transmission symbols to half symbols,  
0 and transmits the generated symbols to the transmission path  
via the D/A conversion section 64.

On the other hand, on the receiver side, upon receiving the received symbols via the A/D conversion section 71, the half symbol demodulation section 72 demodulates the received symbols according to a procedure similar to that of the first embodiment. Since the A/D conversion section 71 has a configuration similar to Fig. 1 in the first embodiment, the same numerals are used and explanation thereof will be omitted. A demodulated signal is represented by  $[y_{2i-1}, y_{2i}]$ . In the half symbol demodulation section 72, energy of either of adjacent subcarriers (which correspond to, for example, subcarrier #1 and subcarrier #2, subcarrier #3 and subcarrier #4, ...) is certainly 0. Odd-numbered carriers which is noise components when demodulating even-numbered carriers are reduced. Therefore, the demodulation characteristics

If, for example, the received data is  $[y_1=0, y_2=-1]$ , therefore, a signal after despreading, i.e., the original transmission data  $[d_1, d_2]$  becomes,

$$d_1 = [0, -1] \times [-1, -1] = 1$$

$$d_2 = [0, -1] \times [-1, 1] = -1$$

As for other transmission data as well, calculation is conducted in the same way.

5        Thus, in the present embodiment, the transmitter side spreads (multiplexes) the transmission data. Thereby, energy of either of data assigned to the adjacent subcarriers (which correspond to, for example, subcarrier #1 and subcarrier #2, subcarrier #3 and subcarrier #4, ...) is made  
10 equal to 0. As a result, odd-numbered carriers which is noise components at the time of demodulation are reduced. Therefore, the demodulation characteristics can be remarkably improved in such a state that a high transmission rate is maintained in the same way as the first embodiment.

15        Further, in the present embodiment, since the demodulation characteristics can be remarkably improved as explained above, the difference between the power of the even-numbered subcarriers and the power of the odd-numbered subcarriers, i.e., the SNR can be made so as to satisfy the  
20 relation "SNR of the first embodiment > SNR of the embodiment."

As heretofore explained, according to the present invention, the transmitter side converts a transmission symbol to a half symbol and transmits it. The receiver side separates even-numbered subcarriers and odd-numbered  
25 subcarriers. The receiver side first demodulates only the

received symbol of even-numbered subcarriers converted to the half symbol, then removes the symbol component of the even-numbered subcarriers, and demodulates only the received symbol of odd-numbered subcarriers, This results in an effect that it is possible to obtain such a communication apparatus that compression on the time axis becomes possible and the transmission rate can be remarkably improved.

According to the next invention, a symbol formed of only waveforms of odd-numbered subcarriers is fed back, and odd-numbered subcarriers which is noise components can be removed. This results in an effect that it is possible to obtain such a communication apparatus that the demodulation precision can be improved remarkably.

According to the next invention, the transmitter side  
15 makes energy of either of data assigned to a  $(2i-1)$ th  
subcarrier and a  $2i$ th subcarrier which are adjacent to each  
other equal to 0 by spreading (multiplexing) the transmission  
data. Accordingly, odd-numbered carriers which is noise  
components at the time of demodulation are reduced. This  
20 results in an effect that it is possible to obtain such a  
communication apparatus that the demodulation  
characteristics can be improved remarkably in such a state  
that a high transmission rate is maintained.

According to the next invention, transmission symbols  
25 are converted to half symbols and transmitted. This results

in an effect that it is possible to obtain such a transmitter that the transmission rate can be improved remarkably.

According to the next invention, energy of either of data assigned to a  $(2i-1)$ th subcarrier and a  $2i$ th subcarrier  
5 which are adjacent to each other is made equal to 0. Noise components at the time of demodulation are thus reduced. This results in an effect that it is possible to obtain such a transmitter that the demodulation characteristics can be improved remarkably.

10 According to the next invention, even-numbered subcarriers and odd-numbered subcarriers are separated. First, only the received symbol of even-numbered subcarriers converted to the half symbol is demodulated, then the symbol component of the even-numbered subcarriers is removed, and  
15 only the received symbol of odd-numbered subcarriers is demodulated. This results in an effect that it is possible to obtain such a receiver that the transmission rate can be remarkably improved.

According to the next invention, a symbol formed of  
20 only waveforms of odd-numbered subcarriers is fed back, and odd-numbered subcarriers which is noise components can be removed. This results in an effect that it is possible to obtain such a receiver that the demodulation precision can be improved remarkably.

25 According to the next invention, odd-numbered carriers



which is noise components at the time of demodulation are reduced. This results in an effect that it is possible to obtain such a receiver the demodulation characteristics can be improved remarkably in such a state that a high  
5 transmission rate is maintained.

According to the next invention, the transmitter side converts a transmission symbol to a half symbol and transmits it. The receiver side separates even-numbered subcarriers and odd-numbered subcarriers. The receiver side first demodulates only the received symbol of even-numbered subcarriers converted to the half symbol, then removes the symbol component of the even-numbered subcarriers, and demodulates only the received symbol of odd-numbered subcarriers. This results in an effect that it is possible to obtain such a communication method that compression on the time axis becomes possible and the transmission rate can be remarkably improved.

According to the next invention, a symbol formed of only waveforms of odd-numbered subcarriers is fed back, and odd-numbered subcarriers which is noise components can be removed. This results in an effect that it is possible to obtain such a communication method that the demodulation precision can be improved remarkably.

According to the next invention, the transmitter side  
25 makes energy of either of data assigned to a  $(2i-1)$ th

subcarrier and a 2ith subcarrier which are adjacent to each other equal to 0 by spreading (multiplexing) the transmission data. Accordingly, odd-numbered carriers which is noise components at the time of demodulation are reduced. This results in an effect that it is possible to obtain such a communication method that the demodulation characteristics can be improved remarkably in such a state that a high transmission rate is maintained.

#### 10 INDUSTRIAL APPLICABILITY

As heretofore described, the communication apparatus and the communication method are useful to data communication using existing communication lines by means of the DMT (Discrete Multi Tone) modulation and demodulation technique and OFDM (Orthogonal Frequency Division Multiplex) modulation and demodulation technique. The communication apparatus and the communication method are suitable not only for communication apparatuses which conduct data communication by using the DMT modulation and demodulation technique, but also for every communication which conducts wire communication and radio communication via an ordinary communication line by using a multicarrier modulation and demodulation technique and a single carrier modulation and demodulation technique.